What caused the spatial variability of strong ground motions near the epicentre of 2016 M7.8 Kaikōura earthquake? The role of the local geologic condition

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Abstract

During the 2011 M7.8 Kaikōura earthquake, ground motions recorded near the epicentre showed a significant spatial variation. The Te Mara farm (WTMC) station, nearest to the epicentre, recorded 1g and 2.7g of horizontal and vertical peak ground accelerations (PGA), respectively. The nearby Waiau Gorge (WIGC) station recorded a horizontal PGA of 0.8g. Interestingly, however, the Culverden Airlie Farm (CULC) station that was very closely located to WIGC recorded a horizontal PGA of only 0.25g. This poster demonstrates how the local geologic conditions could have contributed to the spatially variable ground motions observed in North Canterbury, based on the results of recently conducted geotechnical and geophysical investigations.

Observation

- Station WTMC recorded the largest acceleration (1g horizontal and 2.7g vertical peak accelerations); it was very closely located to a surface rupture.
- WIGC recorded a significantly higher PGA than CULC, even though the source-to-site distances of the two stations are very similar.
- Long period spectral accelerations of WIGC and CULC are very similar; however spectral accelerations at WIGC is much larger in short vibration periods (T<2s), which suggests site effects.
- All three sites show strong vertical spectral accelerations at short periods; amplification of short period spectral accelerations at WIGC compared with CULC is also observed in the vertical component.

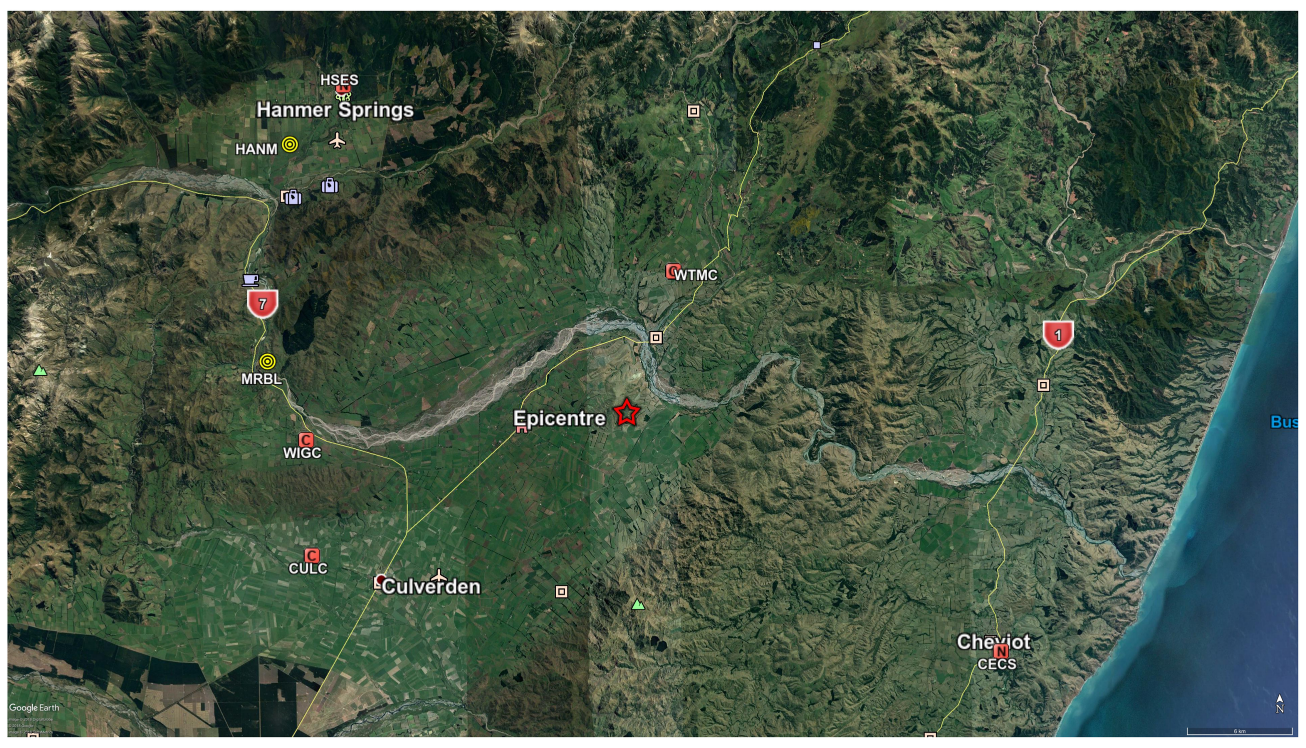

Figure 1: Map showing the epicentre of the Kaikōura earthquake and the nearby strong motion stations.

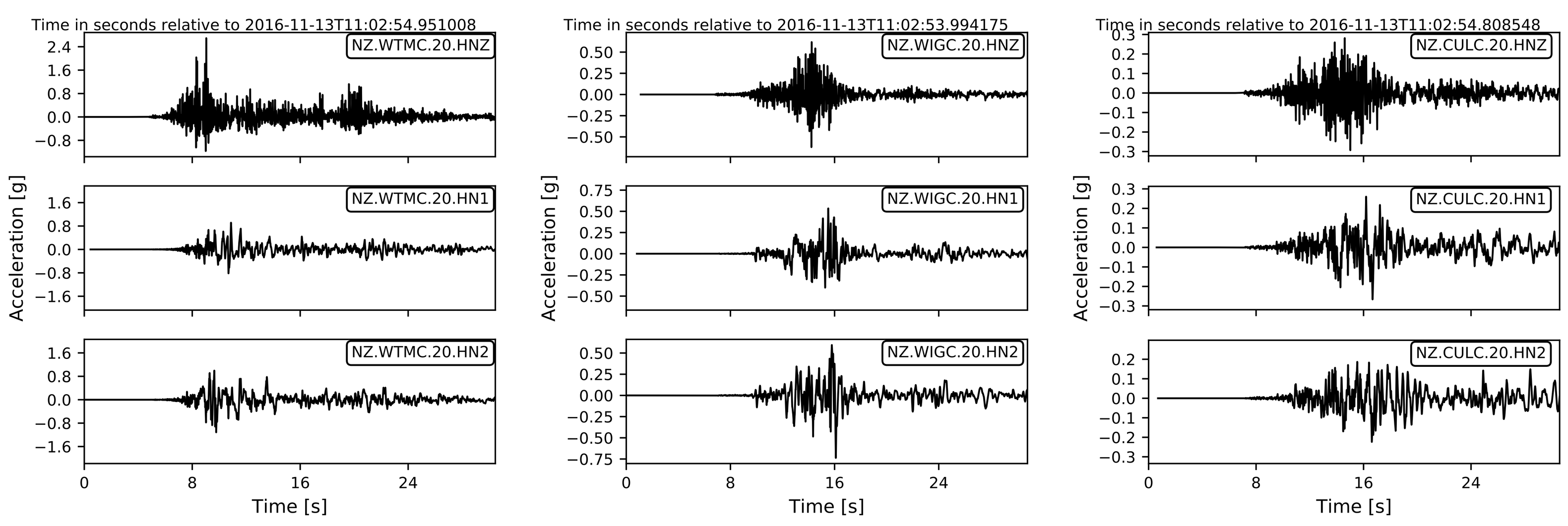

Figure 2: Recorded acceleration time series at stations WTMC, WIGC and CULC.

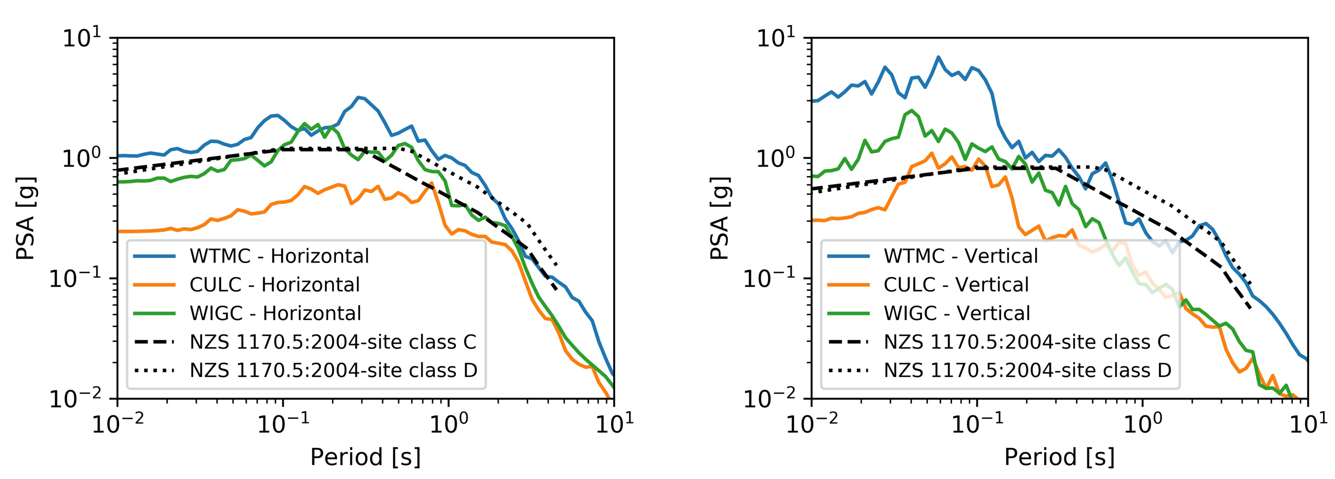

Figure 3: Recorded response spectra at stations WTMC, WIGC and CULC. NZS 1170.5:2004 elastic design spectra with the annual probability of exceedance 1/500 with a zone factor of 0.4 are shown for reference.

Site investigation

The surficial geology of this area is dominated by alluvial gravel deposits with traces of silt. To characterise the dynamic properties of the sedimentary basin, we conducted active and passive source surface wave testing at the three strong motion stations. We also drilled a borehole at WTMC and conducted a seismic downhole test. Surface wave testing at each site consisted of three 2D circular passive arrays of different radii (50m, 150m and 350m) with eight Nanometrics Trillium compact 20s seismometers and a linear 48m 24 channel active source geophone array. The array configuration at WTMC and the location of the borehole are shown in Figure 4(a).

We used the Geopsy software (http://geopsy.org) to perform the inversion analysis, using the combined dispersion curves from the arrays of different radii and geometry. A-priori information about the local geology was used to constrain the inversion parameters.

Site investigation–continued

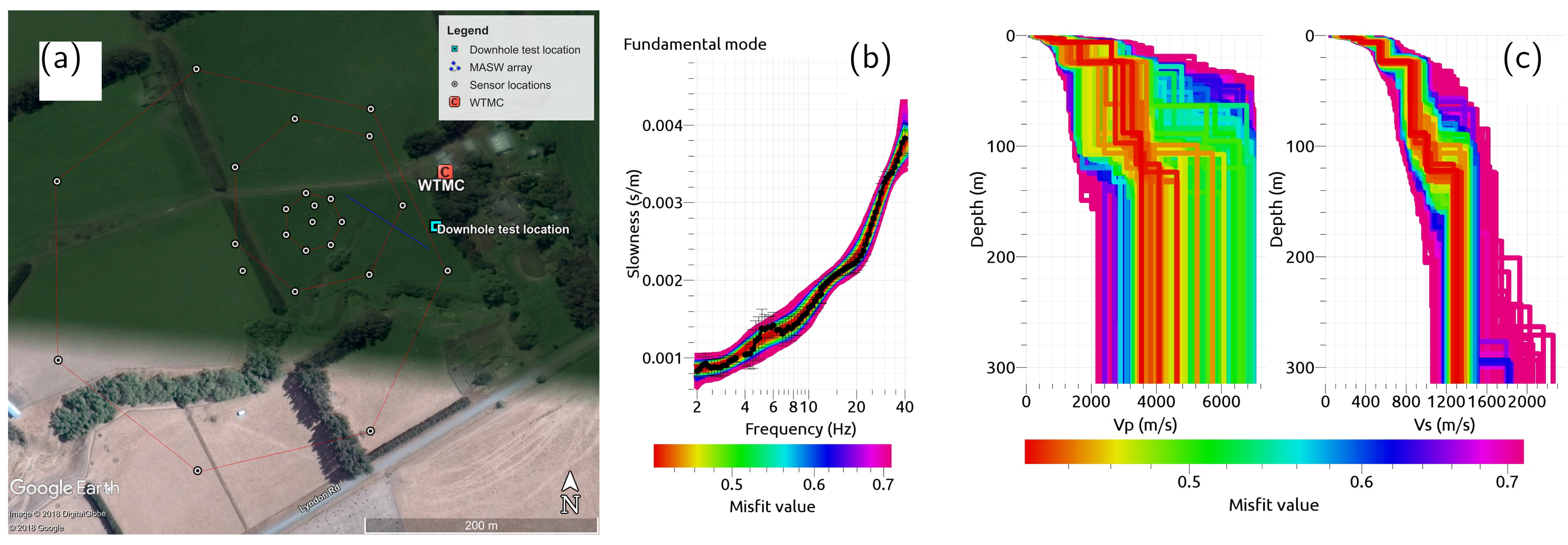

Figure 4: (a) Map of the sensor array, borehole location, and the location of WTMC, (b) fundamental mode Rayleigh wave dispersion curve, and (c) Vs and Vp profiles obtained by the inversion.

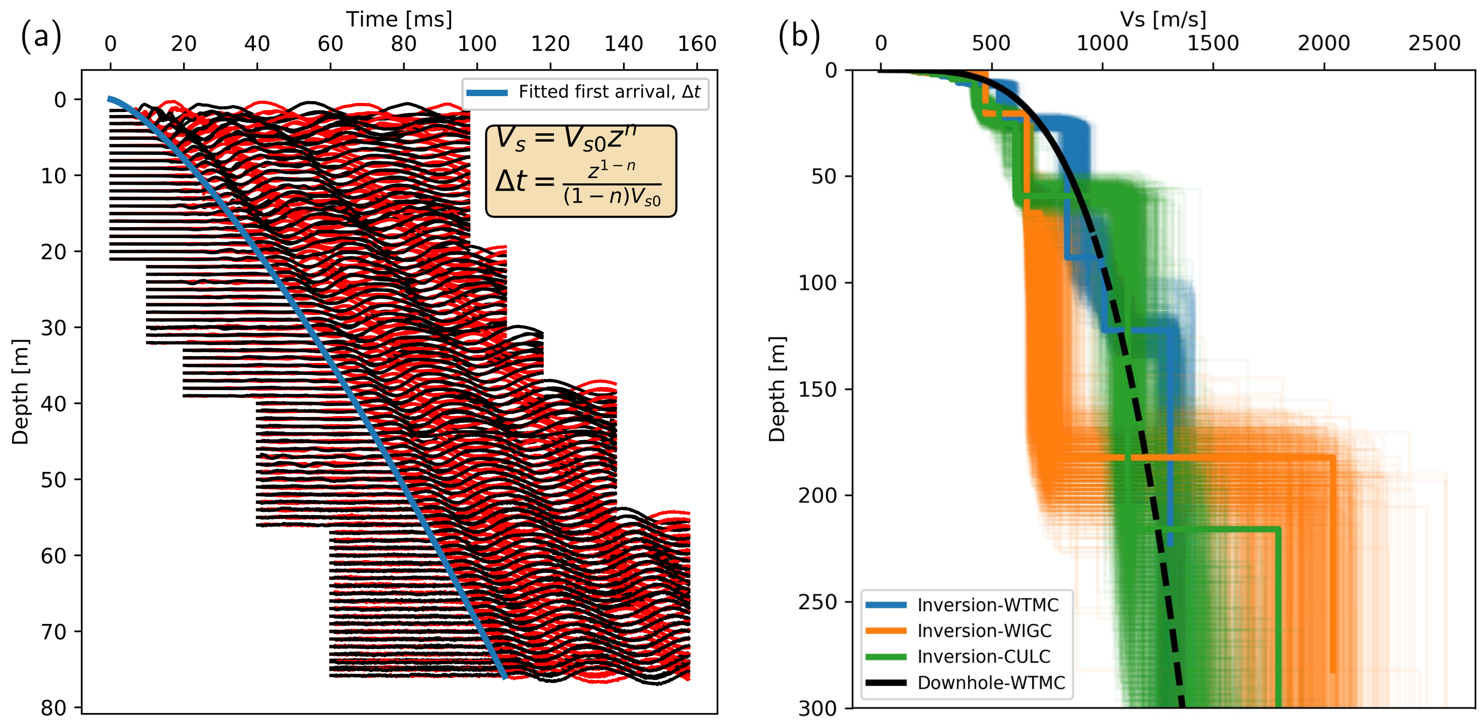

Figure 5: (a) Waterfall plot of the Vs downhole test waveforms and the fitted first arrival curve, and (b) comparison of the WTMC downhole Vs profile and the surface wave testing. 1000 best profiles out of one million trials are shown for each site. The downhole test was ended at 76m; the dashed line shows the extension of the fitted power law model.

- The borehole log at WTMC confirmed that the surficial geology is dominated by angular alluvial gravels, mixed with sands and silts. The borehole log also showed that the thickness of the sediments at WTMC is over 76 metres.
- The Vs profile from the downhole test was obtained by assuming a power law model as shown in Figure 5(a) and by least-squares fitting the travel time equation to the hand-picked first arrival times. Figure 5(a) shows that the power law model is consistent with measured first arrival times.
- The downhole test result is broadly consistent with the inverted Vs profile of WTMC. Interestingly, the result of downhole test at WTMC suggests unusually high shear wave velocity of the gravelly sediments.
- The inversion analysis suggests a large impedance contrast at WIGC at a depth between approximately 160m and 210m; such a large contrast was not present in Vs profiles of WTMC or CULC.

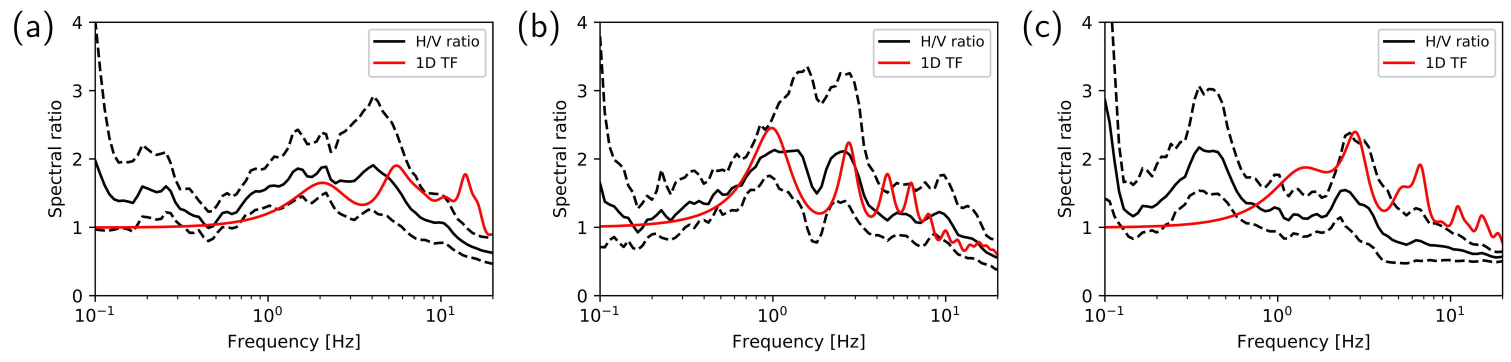

Figure 6: Ambient vibration horizontal-to-vertical (H/V) spectral ratios at (a) WTMC, (b) WIGC, and (c) CULC. 1D transfer functions of the minimum misfit Vs profiles are shown for comparison.

- The 1-dimensional transfer functions are broadly consistent with the measured H/V spectral ratios, considering that they are not expected to be identical.
- The current Vs profile at CULC, which had the depth limit of 300m, appears incomplete. The H/V ratio shows a peak at f=0.4Hz, which is missing in the current 300m Vs profile.

Discussions

We investigated the relationship between the observed spatial variation of ground motion intensities in the epicentral area of the 2016 M7.8 Kaikoura earthquake and the site dynamic characteristics defined via geotechnical and geophysical investigation.

The strongest motion was recorded at WTMC. However, the Vs profile and the 1D transfer function from the downhole test and the surface wave inversion suggest that the site amplification may not be strong at this site, which suggests that the high intensity of the recorded motion at this stations was primarily due to the proximity to the causative fault.

Comparisons of H/V spectral ratios and Vs profiles suggest that the sediment thickness is much smaller at WIGC compared with CULC; the high PGA at WIGC was likely influenced by the high-frequency amplification caused by the response of shallow sediments above a large impedance contrast.

Acknowledgements

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